

EXOPLANET EXPLORATION PROGRAM ANALYSIS GROUP #10,Boston, MA

Exoplanet Exploration Program Update

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Jet Propulsion Laboratory, California Institute of Technology

June 6, 2014

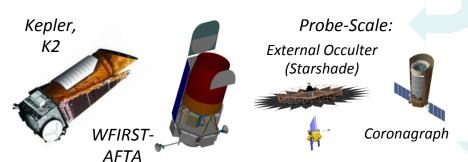
The Exoplanet Exploration Program: Exploring New Worlds



ExoPlanet Exploration Program

Exploring How the Universe Works **Discovering** and Characterizing Exoplanets **Searching** for Signs of Life in the Galaxy

Space Missions and Mission Studies



Public Engagement



Supporting Research & Technology

Key Sustaining Research



Keck Single Aperture Imaging and RV



Large Binocular Telescope Interferometer

Technology Development



High Contrast Imaging



Deployable Star Shades

Archives, Tools & Professional Education



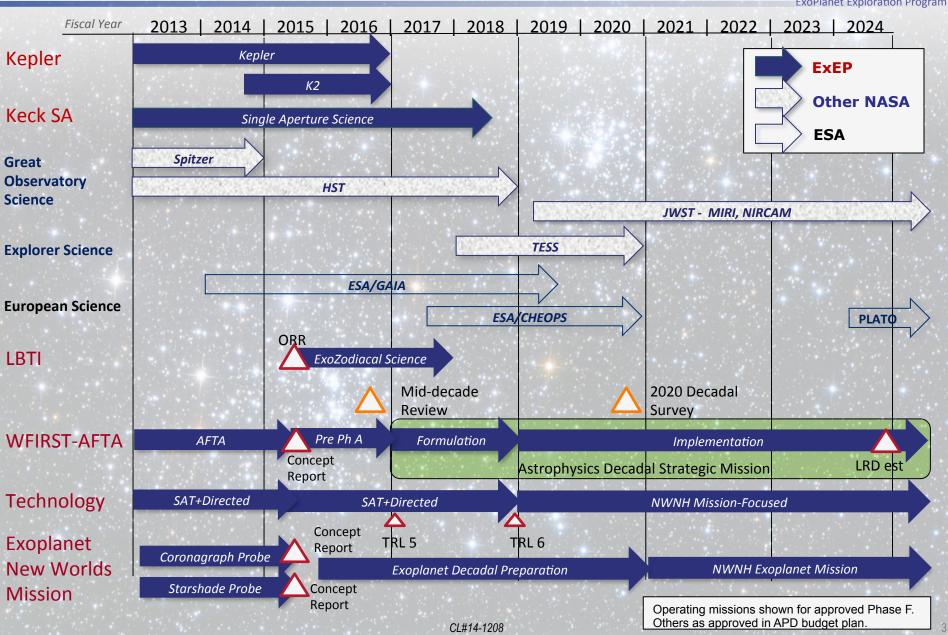
NASA Exoplanet Science Institute

URSCL#14-0506

Exoplanet Exploration: A Decade Horizon NASA and **ESA** efforts



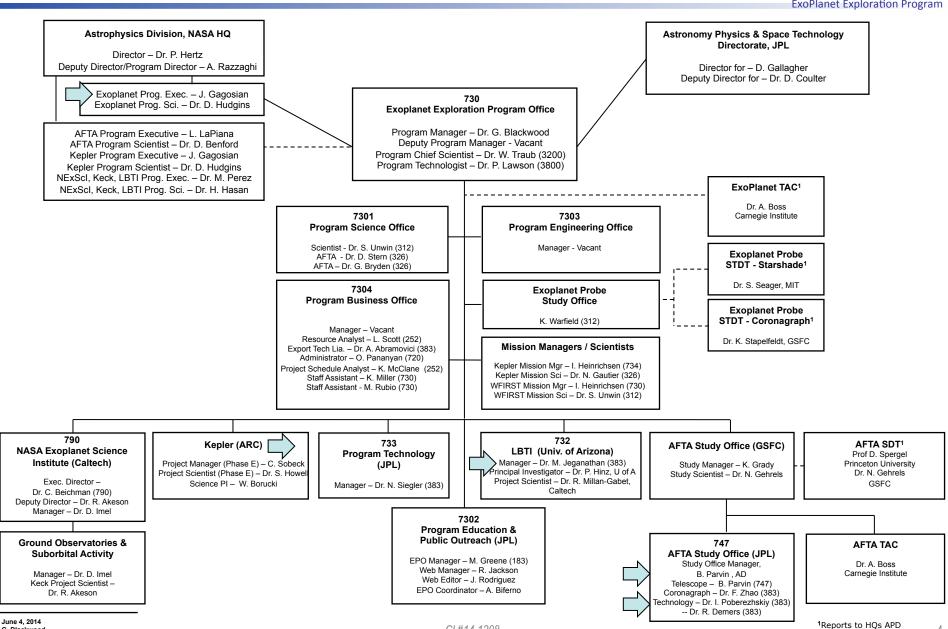
ExoPlanet Exploration Program



Exoplanet Exploration Program Organization Chart



ExoPlanet Exploration Program



G Blackwood **Exoplanet Exploration Program**

Recent Highlights



ExoPlanet Exploration Program

Program Management

- Technology Plan Appendix published with prioritized gap lists
- Delivered budget plan (PPBE) for FY15-19 on May 1,2

Kepler

- Kepler-186f: likely rocky planet (1.1 earth radii) in habitable zone of M-star
- K2 mission selected by Senior Review, completed Tile-0 observations

WFIRST-AFTA

- Delivered interim report and technology plan
- Held AAS Conference-in-Conference "On the Shoulders of Giants" June 2014

Probe Studies

Delivered interim reports for Exo-C and Exo-S

Technology

- Low Order Wavefront Sensing and Control (LOWFSC) meeting held at JPL
- Assessed that funds are likely sufficient to deliver TRL5 by FY18 for probe-class starshade (TDEM), or by FY17 for probe- or AFTA-coronagraph (directed)

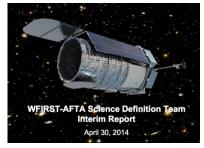
NExScI

New Sagan Fellows announced

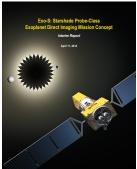
• LBTI:

- Reached 36 zodi performance level (relative to PLRA requirement of 3 zodis).
 ORR postponed from March 2014 to April 2015
- Completed risk assessment / mitigation review











WFIRST AFTA Status



ExoPlanet Exploration Program



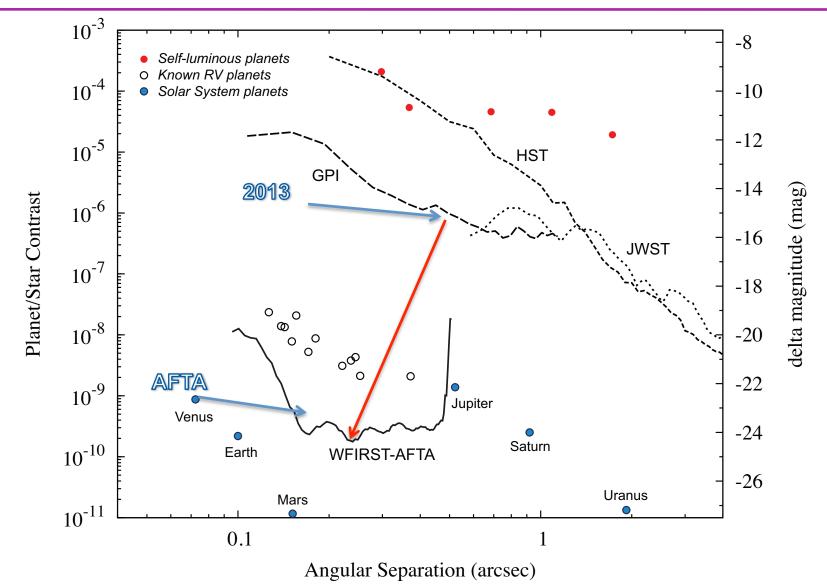


- The WFIRST-AFTA Science Definition Team (SDT) held a face-to-face meeting April 1-2. The next is schedule for July 24-25.
- The project continues to work with the SDT on defining Level 1 and 2 requirements.
- The SDT with support from the project completed and delivered the WFIRST/AFTA Interim Study Report
- Design Cycle4 is underway now. Includes Wide Field Instrument grism and Coronagraph in first real design cycle [as part of Cycle4]
- The Coronagraph TAC was briefed on March 24th on the Coronagraph Technology Plan
- The Detector TAC was briefed on April 3rd on the Detector Development Plan
- Scientists have been exploring potential collaborations with Japan, ESA, and Canada



Coronagraph Tech Development Path







Coronagraph Key Milestones



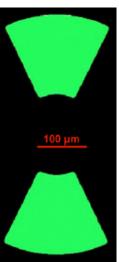
MS#	Milestone	Date		
1	First-generation reflective Shaped Pupil apodizing mask has been fabricated with black silicon specular reflectivity of less than 10^{-3} and $20~\mu m$ pixel size.	7/21/14		
2	Shaped Pupil Coronagraph in the High Contrast Imaging Testbed demonstrates 10 ⁻⁸ raw contrast with narrowband light at 550 nm in a static environment.	9/30/14		
3	First-generation PIAACMC focal plane phase mask with at least 12 concentric rings has been fabricated and characterized; results are consistent with model predictions of 10 ⁻⁸ raw contrast with 10% broadband light centered at 550 nm.			
4	Hybrid Lyot Coronagraph in the High Contrast Imaging Testbed demonstrates 10 ⁻⁸ raw contrast with narrowband light at 550 nm in a static environment.	2/28/15		
5	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10 ⁻⁸ raw contrast with 10% broadband light centered at 550 nm in a static environment.	9/15/15		
6	Low Order Wavefront Sensing and Control subsystem provides pointing jitter sensing better than 0.4 mas and meets pointing and low order wavefront drift control requirements.	9/30/15		
7	Spectrograph detector and read-out electronics are demonstrated to have dark current less than 0.001 e/pix/s and read noise less than 1 e/pix/frame.	8/25/16		
8	PIAACMC coronagraph in the High Contrast Imaging Testbed demonstrates 10 ⁻⁸ raw contrast with 10% broadband light centered at 550 nm in a static environment; contrast sensitivity to pointing and focus is characterized.	9/30/16		
9	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10 ⁻⁸ raw contrast with 10% broadband light centered at 550 nm in a simulated dynamic environment.	9/30/16		

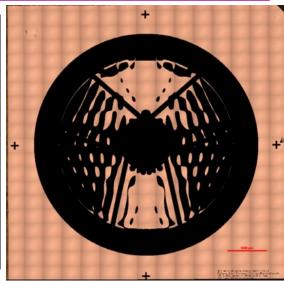


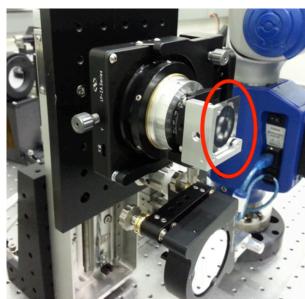
SPC Progress: Reflective Mask



- Mask design delivered from Princeton and translated into machine language
- Successfully fabricated first sets of SP masks (March 2014). Four iterations of reflective shaped pupil masks fabricated at JPL and Caltech
 - Reduced defects from earlier to later iterations due to process improvements
- Measured Si wafer wavefront error, identified acceptable 4" wafers
- Developed mounting approach, built reflective shaped pupil mount, measured WFE stability
- Measured Black Si specular reflectivity (<<10⁻⁴)
- Fabricated transmissive field stops
- Modeling the effects of imperfections in the fabricated mask on coronagraph contrast after wavefront control
- Shaped Pupil mask for coronagraph testbed was delivered to testbed on schedule (April 3, 2014)



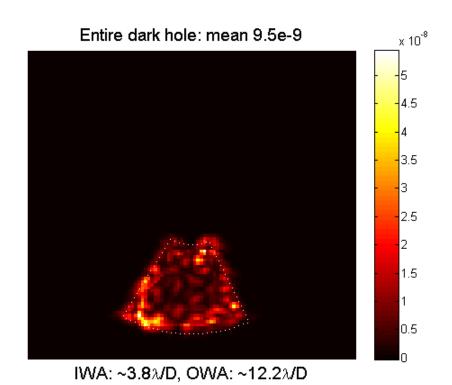






Initial Shaped-Pupil Mask Coronagraph Result

- The AFTA coronagraph using a newly fabricated reflective Shaped-Pupil Mask met its milestone performance of < 1e-8 raw contrast ratio with monochromatic light in the High Contrast Imaging Testbed at JPL (see below).
 - This mask was designed to accompany the AFTA obscured pupil
 - Work is continuing to push to even greater contrast and smaller inner working angles as a second deformable mirror will be added in August
 - The team is preparing to now move to broadband light demonstrations



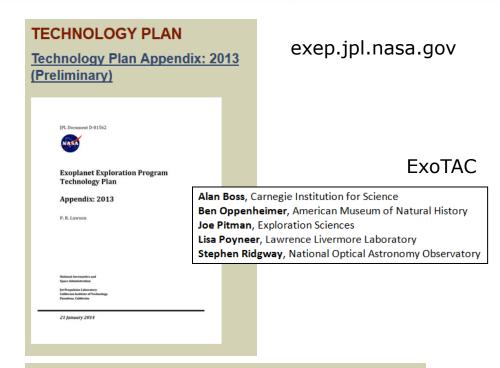
Technology Progress Through TDEM



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JPL PI WBS		NICKNAME	
		TDEM 2009	
	Martin	Mid-IR Interferometric planet detection, instability noise	
09.01.12	Noecker/Kendrick	Speckle measurement algorithms & Pin-Hole Method	
09.01.04	Trauger	Hybrid Lyot Masks, broad-band starlight suppression	
GSFC/HQ	Guyon	PIAA Low-order WF Sensor	
09.01.16	Kasdin	Starshade petal manufacturing	
09.01.03	Krist	Efficient Coronagraph Modeling (MS #1)	
09.01.03	Krist	Efficient Coronagraph Modeling (MS #2)	
GSFC/HQ	Figer	Avalanche Photo-diode arrays, radiation testing	
09.01.08	Guyon	PIAA, monochromatic suppression	
GSFC	Clampin/Lyon	Visible Nulling Coronagraph	
		SAT/TDEM 2010	
10.34	Serabyn	Vector Vortex Masks, starlight suppression in HCIT	
10.33	Sandhu	Visible Nulling Coronagraph, starlight suppression	
non-TDEM	Schneider	EXCEDE (Explorer supported)	
10.35	Shaklan	TPF-C MS #3A, Lyot Mask model sensitivity validation	
10.31	Kasdin	Starshade deployment demonstration	
10.41	Kasdin	2 DMs starlight suppression	
HQ	Bierden	MEMS deformable mirrors	
HQ	Helmbrecht	Testing of MEMS DMs	
10.29	Guyon	PIAA, broadband starlight suppression	
GSFC	Lyon	Visible Nulling Coronagraph broadband testing	
		SAT/TDEM 2012	
HQ	Casement	Starshade edge scattering	
HQ	Glassman	Optical Model Validation "Field Test"	
	Kasdin	Optical and Mechanical Verification of External Occulter	
		SAT/TDEM 2013	
		SAT/TDEM 2014	

	Completed
\bigcirc	Will complete FY14
\bigcirc	Planned complete > FY14



STRATEGIC ASTROPHYSICS TECHNOLOGY AWARDS

Exoplanet Technology Research funded through the Technology Development for Exoplanet Missions component of NASA's solicitation on Strategic Astrophysics Technology. Awards for calls from 2009 and 2010 are listed. Links are provided to the abstracts of the original proposals and to the milestone whitepapers, where available.

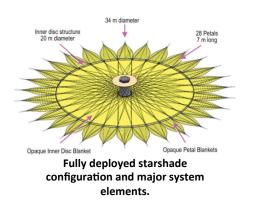
Year	PI	Institution	Proposal Title		
CORONAGRAPH STARLIGHT SUPPRESSION TECHNOLOGY					
2009	Olivier Guyon	Univ. of Arizona	Phase-Induced Amplitude Apodization Coronagraphy Development and Laboratory Validation Abstract Whitepaper #1 Milestone #2		
2009	Martin Noecker	Ball Aerospace	Advanced Speckle Sensing for Internal Coronagraphs and Methods of Isolating Exoplanets from Speckles <u>Abstract</u> <u>Whitepaper</u> <u>Report</u>		
2009	John Trauger	JPL/Caltech	Advanced Hybrid Lyot Coronagraph Technology for Exoplanet Missions Abstract Report		

Technology Progress towards High Contrast Imaging



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 Scaled starshade masks (58 cm) has been fabricated to support an NGAS TDEM 12 desert trial this summer (PI Glassman). First desert tests completed 6/2





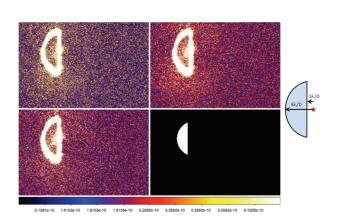
Starshade mask (58 cm diameter); chemically-etched stainless steel



Starshade mask backing structure (58 cm diameter); (not part of flight design)

• The 2010 TDEM Report by Gene Serabyn: successful demonstration of 10⁻⁹ monochromatic contrast using Vector Vortex masks.

Milestone Results from Vector Vortex Demonstrations



Fiscal 2014: SBIR Subtopics S2.01 and S2.02 with mapping to ExEP Coronagraph & Starshade Gap Lists

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ExEP

ExoPlanet Exploration Progra

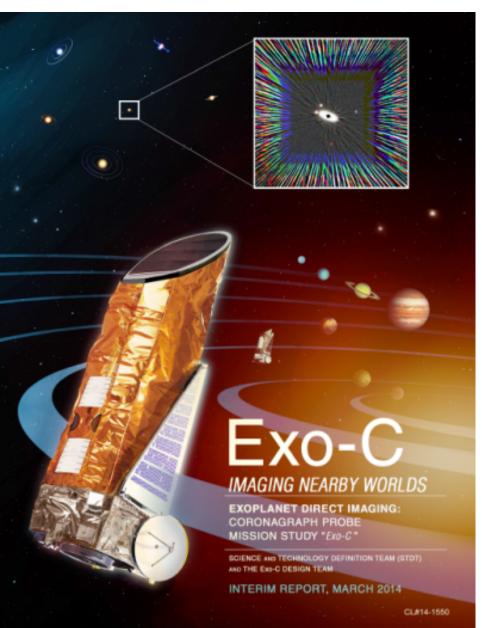
- Subtopic S2.01: Proximity Glare Suppression for Astronomical Coronagraphy
 - Starlight Suppression Technologies (C-1, C-3)
 - C-1: Specialized coronagraph optics
 - C-3: Coronagraph system-level performance demonstration
 - C-6: Post-processing of data
 - S-1: Control of scattered sunlight
 - S-2: Validation of starshade optical models
 - Wavefront Measurement and Control Technologies
 - C-2: Low-order wavefront sensing & control
 - C-5: Deformable mirrors
 - Other
 - C-4: Ultra-low noise detector (technologies for integral field spectroscopy)
- Subtopic S2.02 Precision Deployable Optical Structures and Metrology
 - Architectures, packaging an deployment designs for large sunshields and external occulters
 - S-3: Starshade deployment
 - S-4 Petal deployment demonstration

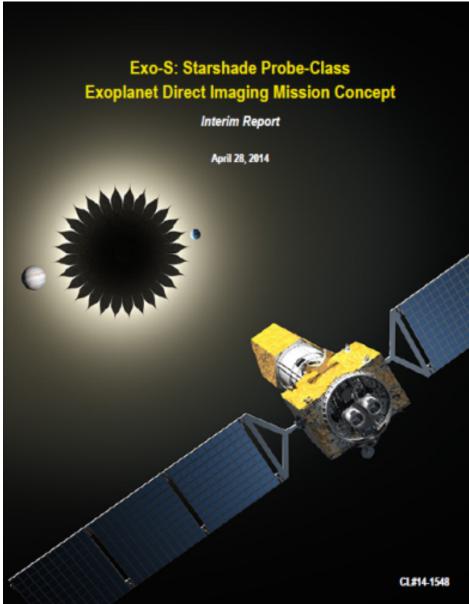
Solicitation opening date: November 14, 2013

Solicitation closing date: January 29, 2014

ExEP





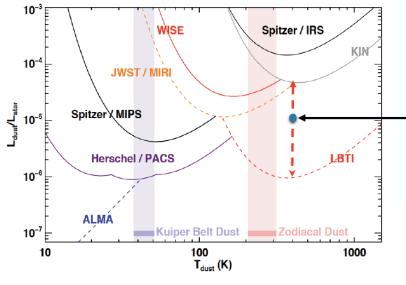


Large Binocular Telescope Interferometer



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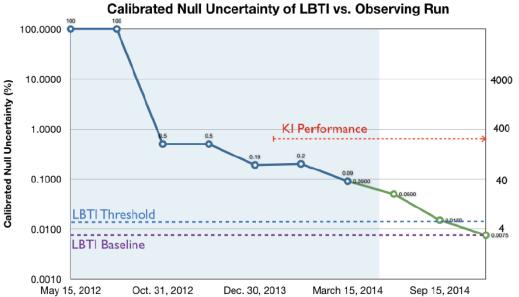




March 2014 Performance

Null UncertaintyPredicted Performance





Dust Brightness (zodies)

Looking Ahead



- 7/21-25 Sagan Summer Workshop: Imaging Planets and Disks, Caltech
- Radial Velocity Search completeness assessment by Andrew Howard (California Planet Search Team) for target lists of AFTA-C, Exo-C, and Exo-S
- Complete PPBE budget process Emphasis on technology plan for TRL5, Kepler closeout, WFIRST-AFTA, Probe studies
- Probe studies:
 - Exo-S: ExEP funding provided to study starshade for AFTA
 - Funding possible for extension in 2015 past final report date
 - Considering funding for special studies, such as retrieval
- Technology: will Confirm TRL5 definition for starshades
- Will advertise for Program Chief Technologist
- Engage Industry and Academia in technology: will convene the Exoplanet Technology Group (ExoTech) in autumn 2014

Exoplanet Technology Group



ExoPlanet Exploration Program

- Engage industry in technology workshop ExEP will convene the Exoplanet Technology Group (ExoTech) in the autumn of 2014:
 - Bring together program technologists and scientists with potential technology providers from industry and academia
 - Program describes technology drivers from design studies, summarizes technology progress, describes prioritized gaps
 - Providers describe capabilities
- Hold conversation about the priorities and plans to most rapidly close the technology gaps
- Results may include
 - Improved input to the next TDEM call
 - Better understanding by all parties on the specific needs requiring quality proposals
 - Design studies benefit from technology push from providers

Acknowledgements



- This was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration. © 2014. All rights reserved.
- Work also carried out by
 - NASA Goddard Space Flight Center
 - NASA Ames Research Center
- Work also carried out by University of Arizona under a contract with the Jet Propulsion Laboratory.
- Work also carried out by Princeton University, University of Arizona and Northrop Grumman Aerospace Systems under contracts with the National Aeronautics and Space Administration.
- Contributions gratefully acknowledged from Karl Stapelfeldt and the Exo-C STDT, and by Sara Seager and the Exo-S STDT, Wes Traub, Peter Lawson, Nick Siegler, Feng Zhao, Steve Unwin, Kevin Grady, Kelly McClane.